# Initial Investigation of RCS Design on Spacecraft Handling Qualities for Earth Orbit Docking

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# Outline

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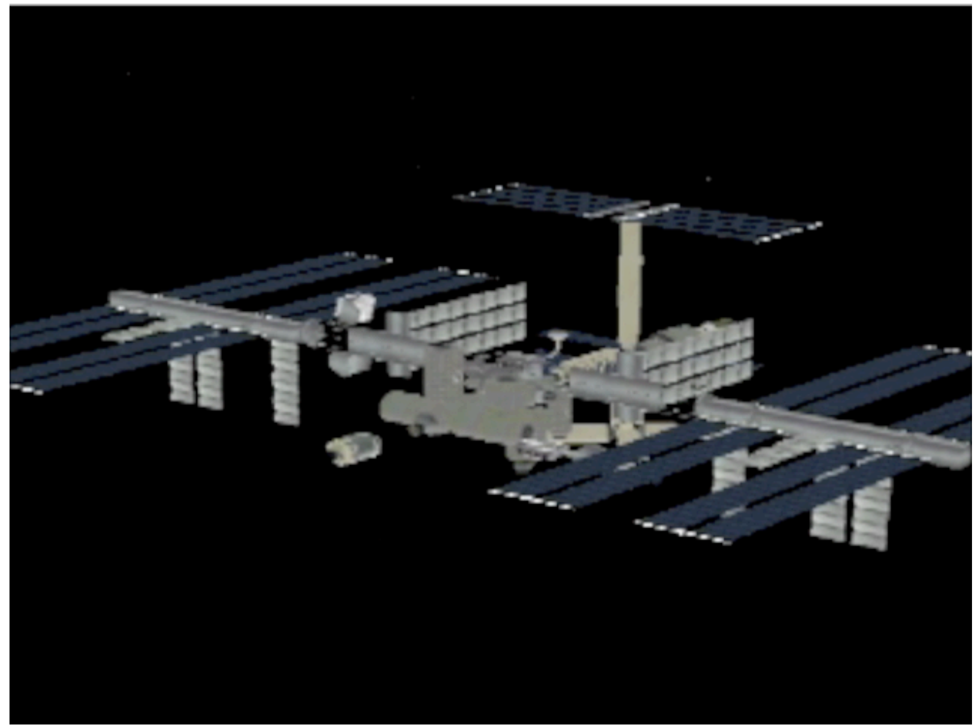


# Introduction

- Handling Qualities (HQ) involve vehicle dynamics, control laws, displays, pilot as a system
- More than just stability & control; includes a measure of pilot workload and task performance
- "Ease and Precision" to perform a task [Cooper & Harper, 1969]
- Worse HQ => increased risk of failure [Hodgkinson, 1995]
- System designers need to know the effect of design decisions upon HQ of a manned vehicle

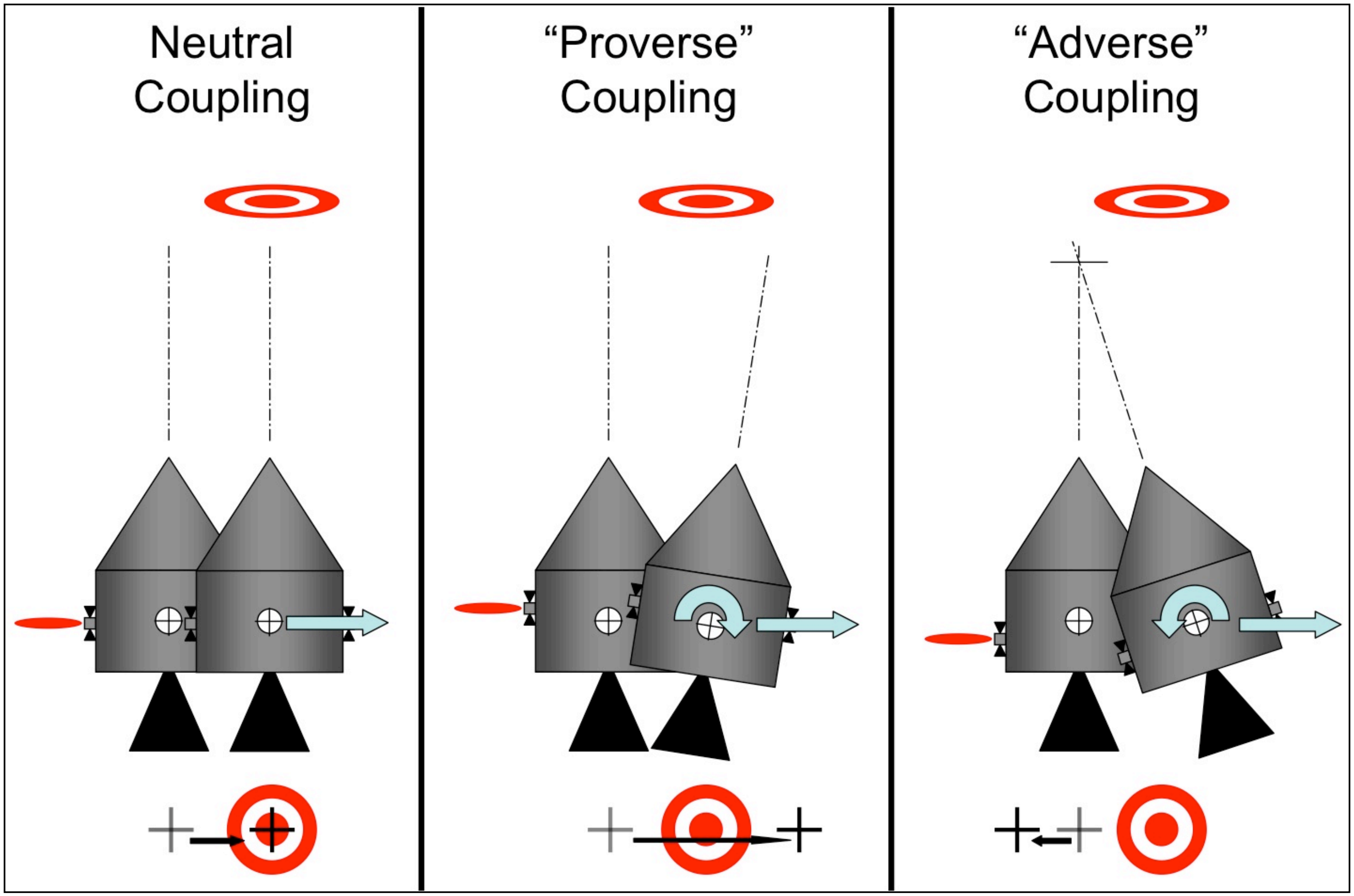
  => Design Guidelines or Standards helpful to avoid costly changes later
- Desire to develop HQ standards for NASA, COTS spacecraft
- This Langley test complemented a similar Ames test of determining HQ for docking task for CEV-***like*** vehicles; second in series (winter 07-08) of four conducted so far

# Background

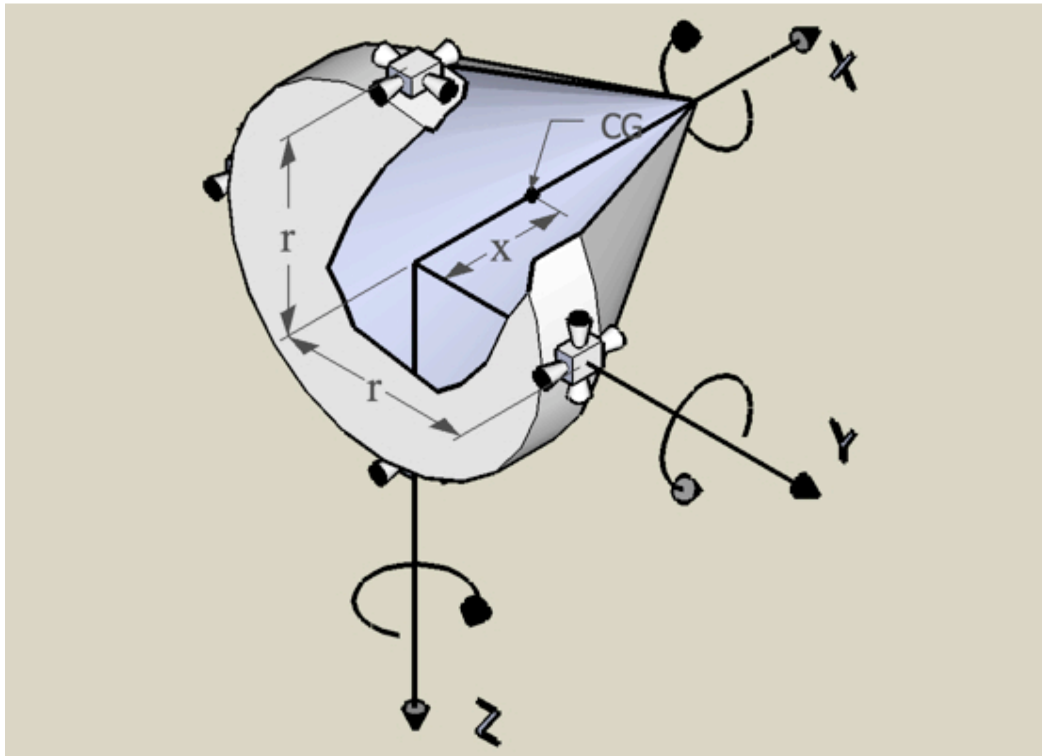
- Existing handling quality (HQ) standards for fixed-wing and rotary-wing (30+ years)
- No such HQ standards for spacecraft
  - Some heritage Gemini, Apollo reports
  - Used earlier Cooper rating scale; did not assess digital control modes
  - HQ issues discovered late in Shuttle design/testing led to “complex workarounds” that could have been mitigated if discovered earlier
- NASA’s new Orion CEV spacecraft to perform automated rendezvous, proximity operations & docking with ISS, lunar surface vehicle
  - Manual crew docking capability must be included (and be Level 1)
- Current CEV RCS design based on trade studies; did not address handling qualities

# Translation into Rotation Coupling

If RCS jets and center of mass are not coplanar => coupling of translation command into uncommanded rotation of spacecraft



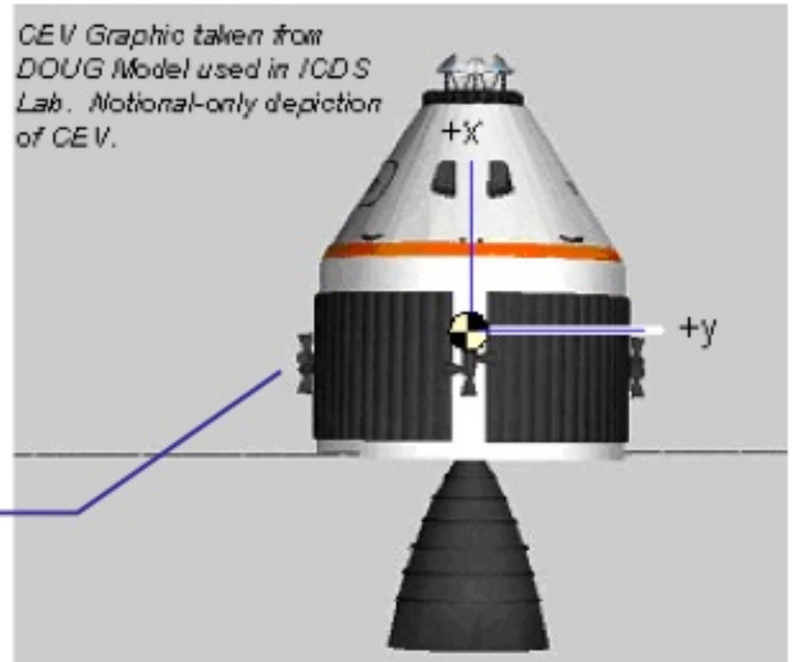
# Vehicle 1: Generic Capsule

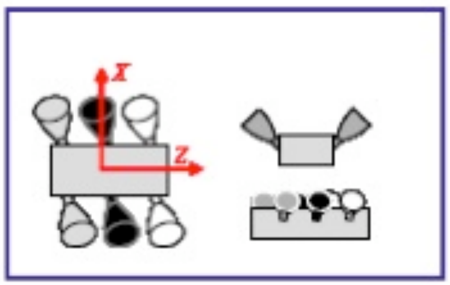



- Apollo-sized vehicle with orthogonal thruster arrangement, fired in pairs
- RCS location moved fore-and-aft to change coupling

# Vehicle 2: ARC/CEV

From AIAA 2007-6684, “Orion Orbit Reaction Control Assessment,” M. Jackson and R. Gonzalez



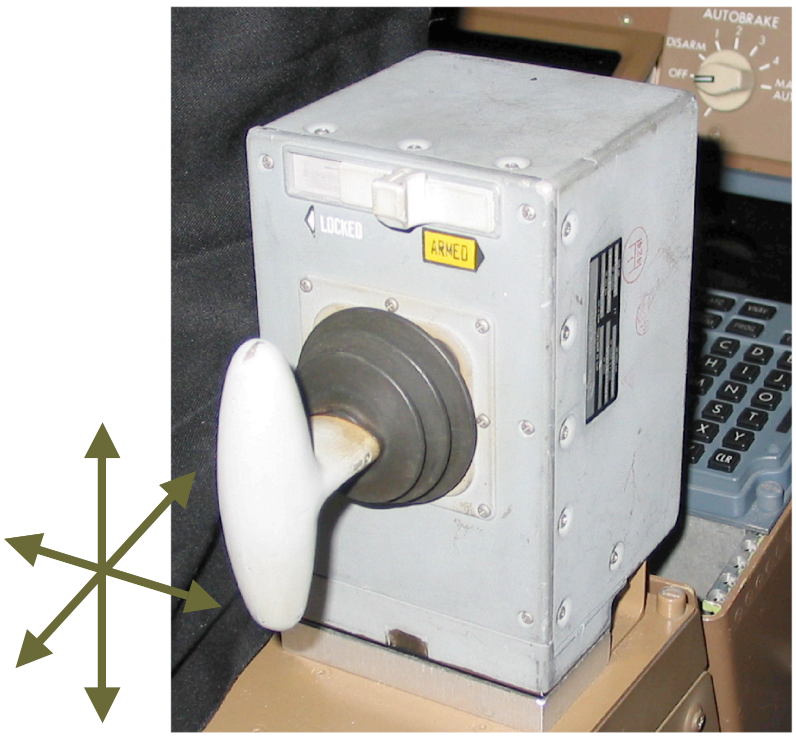

- CEV-***like*** capsule with canted nozzles, duplicative of NASA Ames simulation model
- Fixed RCS, CM location; is Adverse-coupled
- Early design cycle, not indicative of production vehicle; simplified thruster model & control law - *not true CEV*

# Fixed-base Simulator Cockpit

- Repurposed twin-engine transport cab, fixed-base; wide-angle collimated display
- Apollo-era translational and rotational hand controllers
- Masked forward view to match CEV-***like*** window geometry
- Aural range callouts every foot with docking sound

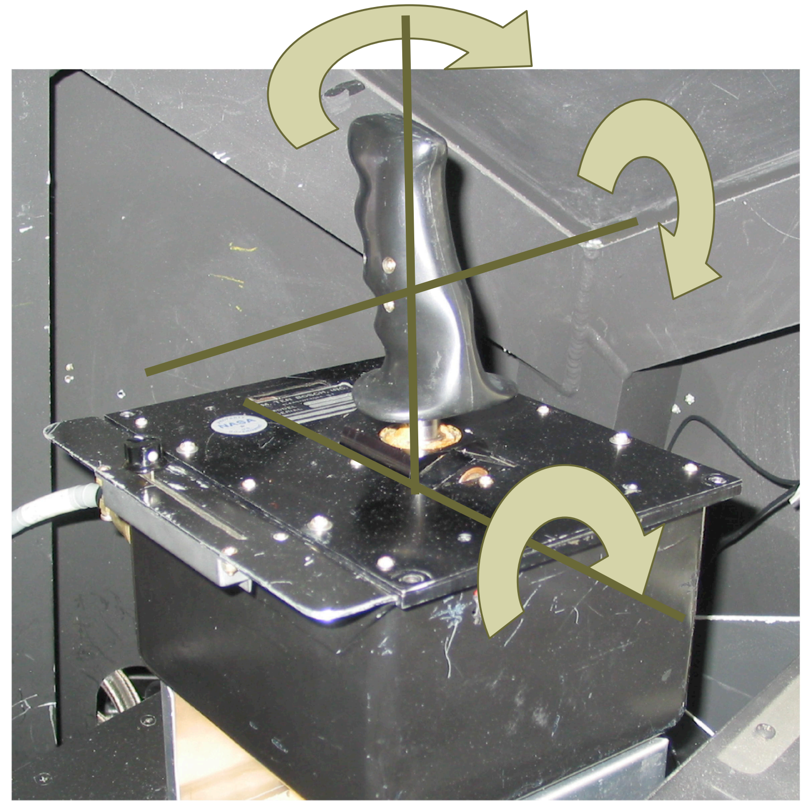
# Inceptors

Translational Hand Controller



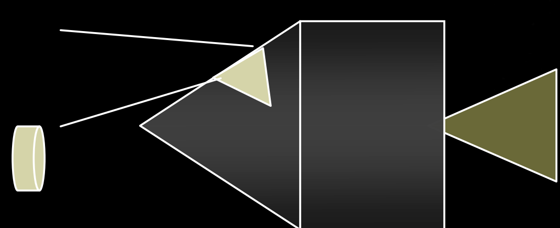

*Continuous jet firings when displaced*

Rotational Hand Controller

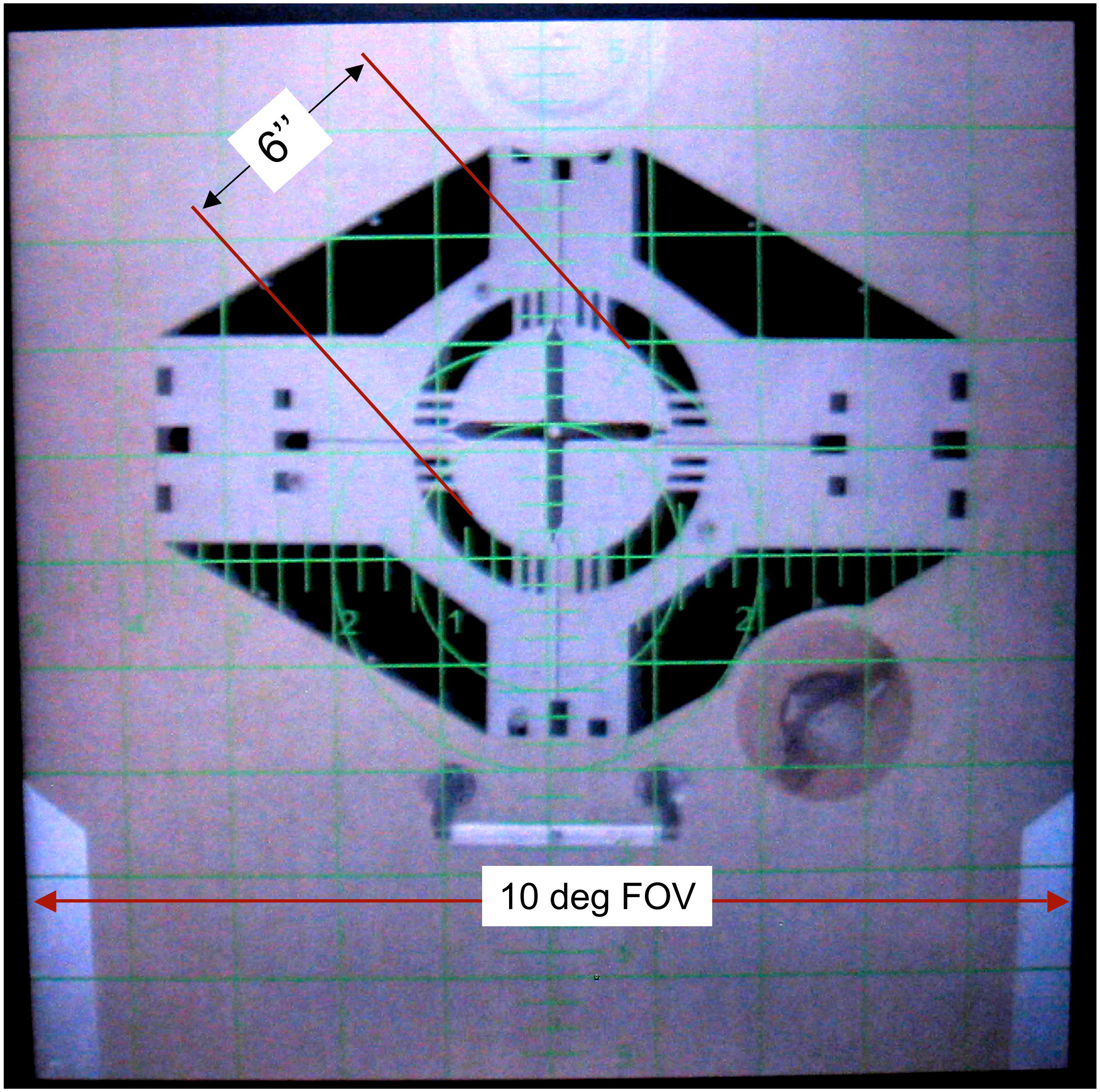


*Adds incremental rate when displaced, or continuous fire at full deflection*

# Exterior View

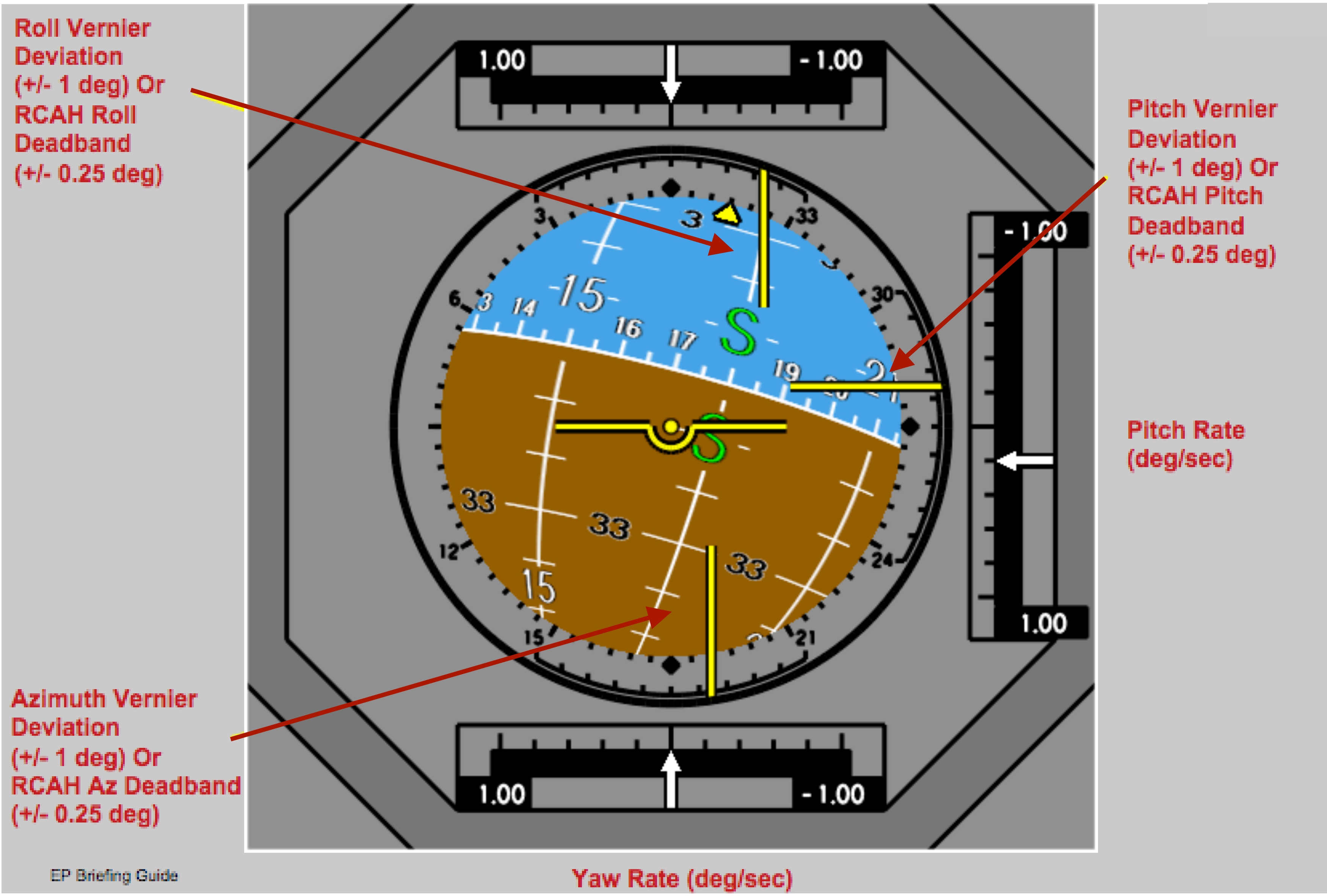


# Centerline Camera Display (head-down)




- Simulated 10 deg fixed field-of-view along the docking port centerline
- Green reticle overlay similar to Shuttle acetate overlay

# Test Description - ADI display

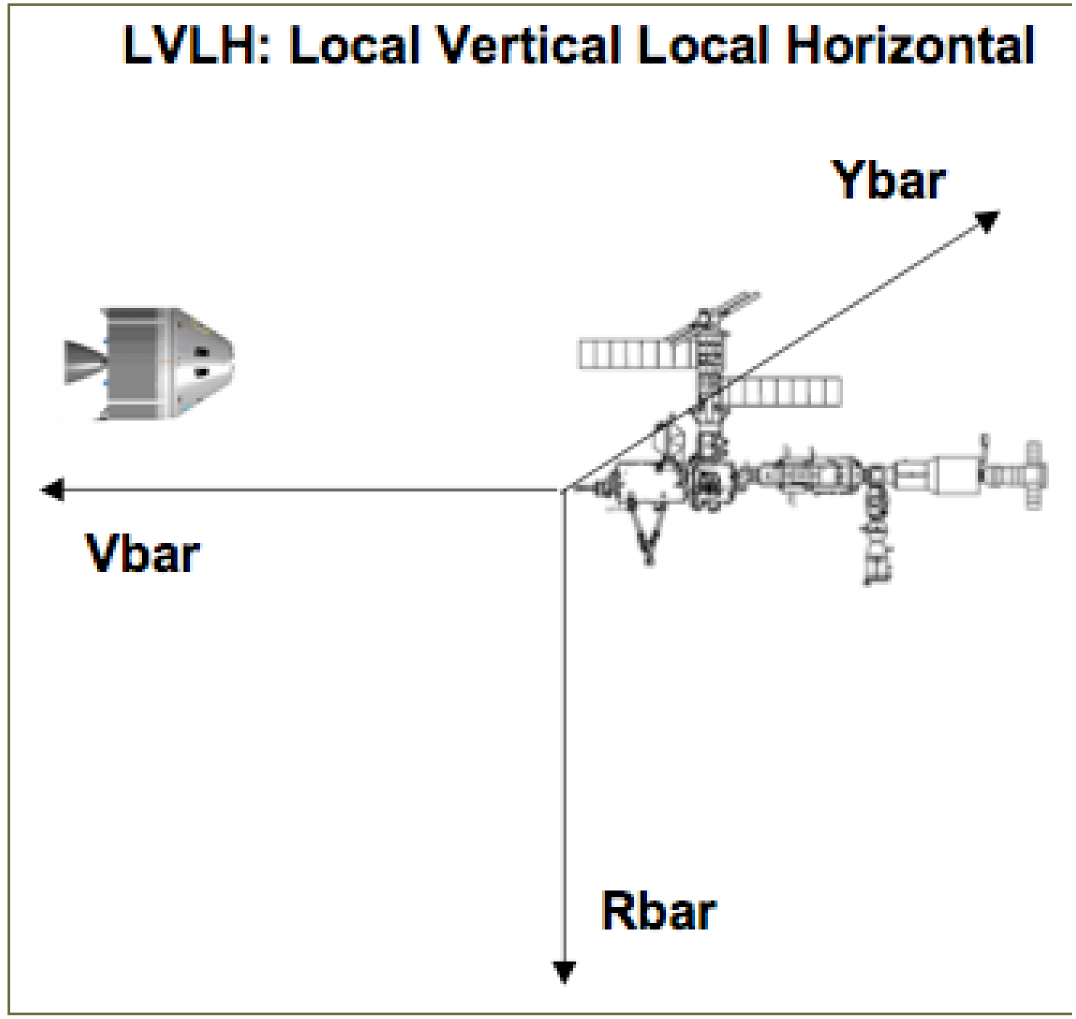


# Test Variations

- Pulse mode: thruster force vs. coupling
  - Used with generic spacecraft (veh. 1) with variable coupling
  - Varied thruster force (double and half of CEV)
  - Two-handed, 6 degree-of-freedom task
- Rotational control mode
  - Used with CEV-***like*** spacecraft (veh. 2) with adverse coupling
  - Half of matrix used RCAH (autopilot) for attitudes (single-handed task)
  - Varied thruster size; turned RCAH autopilot on/off

# Evaluation Tasks

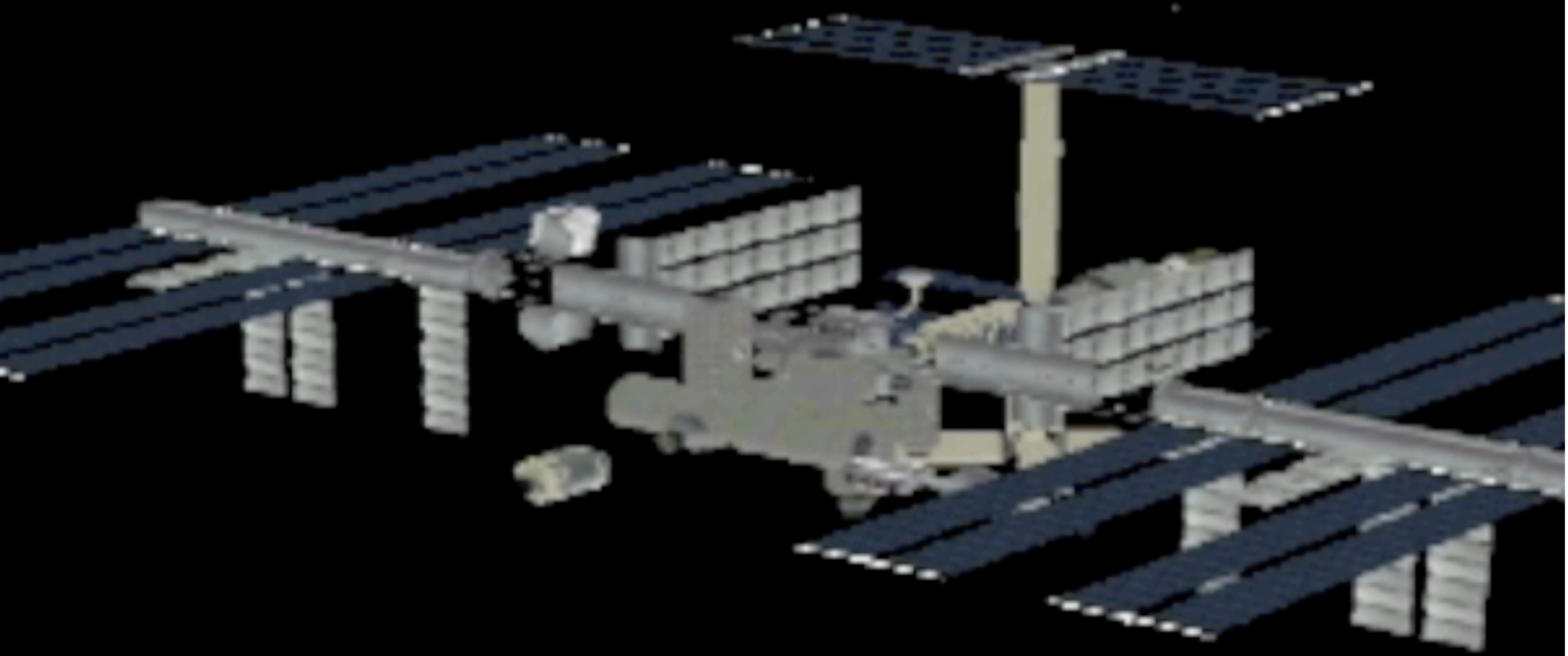
- +Vbar docking with ISS
- Three starting locations: 50, 20, 10 ft from docking
- Offsets of 3 ft lateral/vertical combined
- 0.1 or 0.5 ft/s closure rates; task initialized with this value (Apollo: 1.0 ft/s)
- Orbital effects included (tendency to droop)
- Collected & scored various metrics



# Experimental Protocol

- Ten evaluation pilots
  - Five retired astronauts
  - Three active-duty pilot astronauts
  - Two research (aircraft) USNTPS-trained test pilots
- Up to three hours of training/familiarization
- Each task flown at least once for practice and twice for data
  - More runs for practice or data at EP's request
  - Early configurations repeated if obvious learning seen
- Collected Cooper-Harper, TLX, comments

# Video



# Results: Coupling in Pulse (6 DoF) Mode

- C.L. camera view influenced by both rotation and translation
- Learning curve evident
- Borderline Level 1 - Level 2 with Neutral coupling
- Level 2 - Level 3 with other coupling (Proverse or Adverse)
- Proverse ratings better than Adverse (but possibly tainted by presentation order and learning curve) due to prioritization
- Doubling of control power => degraded performance and ratings, especially for configurations with coupling
- Task load index (TLX) closely tracked Cooper-Harper (CHR) ratings

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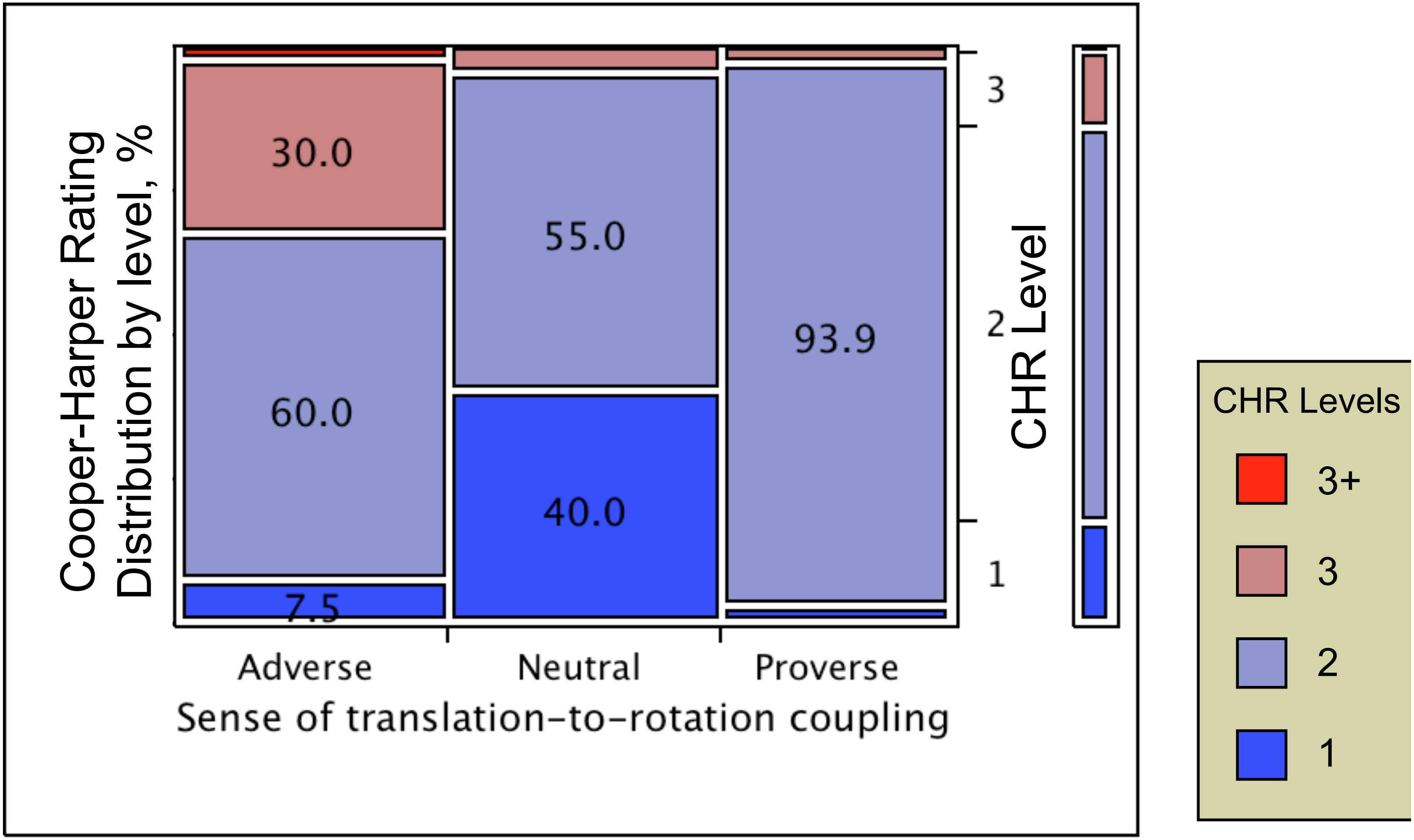

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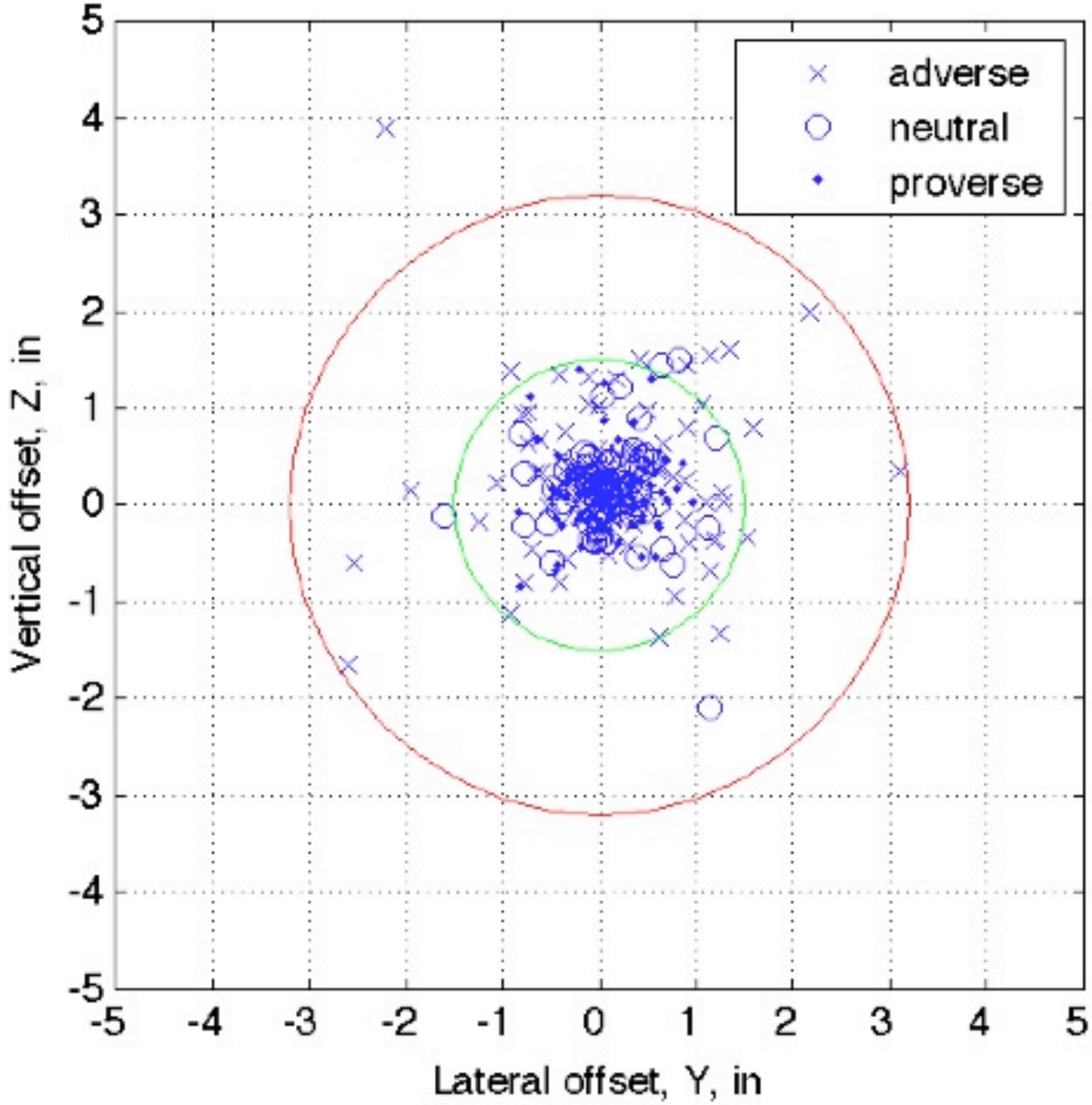

# Results: Rotational Control Evaluations

*Used Vehicle 2 with adverse coupling; initial response is non-minimum phase*

- Rate-command/attitude-hold autopilot (RCAH) adds 'non-deterministic' time delay but improved CHR somewhat
- RCAH attitude deadband made docking somewhat unpredictable
- RCAH gave no appreciable improvement in workload (TLX); compensating for RCAH 'random deadband firing' took a lot of mental effort
- Thruster force variation was not a big effect; slight CHR preference for smaller thrusters (finer control)

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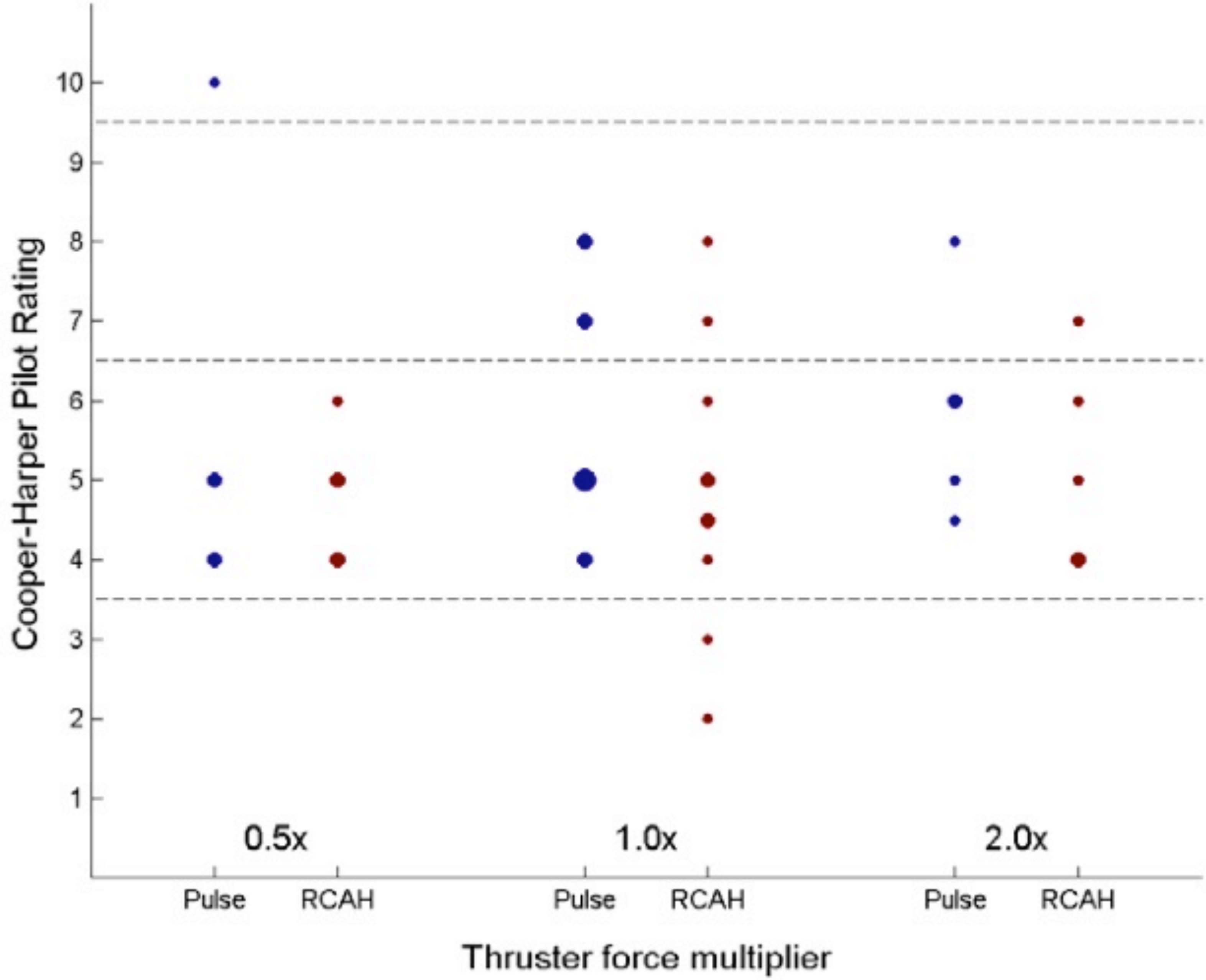

# Concluding Remarks

- Handling Qualities need to be considered in designing any human-operated vehicle
- Location of RCS thrusters have significant HQ effect (requires mitigation of resulting translation-into-rotation)
- Attitude control autopilot, as tested, did not make task Level 1
- For six-degree-of-freedom task (autopilot off), balancing of rotation and translation authority is important
- Adversely coupled spacecraft will require mitigation to achieve Level 1 CHR in manual dockings.

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